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DEFENCE RESEARCH CENTRE SALISBURY
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TECHNICAL MEMORANDUM

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THE PULSE TRANSMISSION MODE LASER

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S U M M A R Y

The Pulse Transmission Mode (PTM) laser has been examined as a possible laser for the WRELADS system under development at the Electronic Research Laboratories of DRCS.

In particular the PTM laser offers a means of generating the short pulses (5 ns FWHM) required by the system but its output is limited by gain saturation to <40 millijoule.

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1. INTRODUCTION

The specification of the laser required for the WRELADS (Weapons Research Establishment Laser Depth Sounder) system is:

PRF	168 Hz
Energy output	5 mJ at 532 nm
Peak power	1 MW at 532 nm
Pulse width	5 ns FWHM
Pump energy	<10 J

During the early phase of the system development at lower repetition rates, (25 Hz), a short cavity conventional laser from the earlier WREMAPS system for land profiling was used.

Extension of existing technology to meet the total specification outlined above was recognised as having difficulties, one of which was the short pulse required . This study was undertaken to assess the suitability of the Pulse Transmission Mode Laser (PTM Laser) as a source of short pulses.

2. DESCRIPTION OF PTM OPERATION

The pulse transmission mode was first proposed by Vuylsteke(ref.1) and was experimentally demonstrated by Hook et al(ref.2,3) with the $Nd:CaWO_4$ and the Nd:Glass laser and Ernest et al(ref.4) with the Ruby laser.

Wentz and Baldwin(ref.5) make a distinction between the pulse transmission mode and cavity dumping. Both types of operation belong to the generic class of coupling modulation, but whilst in cavity dumping the coupling is modulated about some mean level, as is the cavity photon flux, which is never allowed to decay to noise, in the pulse transmission mode the energy is completely drained from the cavity between pulses.

Cavity dumping is frequently used to obtain high peak power, together with high prf from gas lasers and continuously pumped lasers(ref.5 to 9).

In a normal Q switched laser, the pulse risetime and decay time are controlled by the gain, the losses and the cavity length(ref.10), whilst in the PTM laser, the laser cavity is closed with 100% reflectors at either end. The laser is Q switched and the Q switch energy in the cavity rises to a peak. At the instant of peak energy the Q switch is shut very quickly. The stored energy drains from the cavity in the time it takes light to make one round trip of the cavity, (2d/c), where d is the cavity length. The output pulse length is now essentially equal to this time , (2d/c). Figure 1 shows the laser schematically and in figure 2 the switching sequence, stored energy and PTM pulse are indicated. The Q switch loss changes from 1 to 0 in time $T_a < T_d$, the giant pulse evolution time. A second switching operation taking the Q switch loss from 0 to 1 would ideally occur in a time $T_b < 2d/c$. The full width of the pulse is now only a function of the cavity length and would be 5 ns for d = 75 cm.

3. Q SWITCH DRIVE CIRCUIT

Hook et al(ref.3) obtained 4 ns FWHM pulses from Nd:Glass using a dual Krytron circuit. The second switching operation was optically triggered by sensing the leading edge of the Q switch pulse with a high voltage vacuum photodiode. As pointed out by Hook et al, the Krytron is subject to a triggering delay of

the order of 20 ns. In addition the life of the device is limited to approximately 10^5 firings. For these reasons the Krytron was not considered suitable as a switch for our application.

For this investigation an avalanche transistor drive circuit was developed, as described in a previous Technical Memorandum(ref.11). The avalanche chain is shown in figure 3 and the Q switch drive circuit in figure 4.

Initially both optical triggering and electronic triggering with a suitable delay were investigated, and no difference in performance could be discerned. All subsequent work was therefore done with a trigger pulse derived from the timing circuits to activate the second switch.

The measured voltage risetime T_s was 8 ns. As indicated in reference 11 the optical switching speed is faster since the Q switch transmission as a function of time is

$$T(t) = \sin^2 \left\{ \frac{V(t)}{V_{\lambda/4}} \right\}$$

where V(t) is the time dependent voltage across the Q switch and $V_{\lambda/4}$ is the Q switch quarter wave voltage.

Assuming V(t) is a linear ramp of duration Ts, then

$$T(t) = \sin^2 \left\{ \frac{\pi}{2} \frac{t}{T_s} \right\}$$

For T_s = 8 ns the optical risetime , ie the time required for the transmission to change from 10% to 90% is then

$$T_o = 4.7 \text{ ns}$$

4. TEMPORAL SHAPE OF THE PTM PULSE

Hook et al(ref.2) used a simple model for the expected pulse shape in terms of the switching speed, and showed that if, as in figure 2, $T_b \ll 2t_1$ the pulse will be trapezoidal, but if $T_b \gtrsim 2t_1$ it will be triangular.

A more detailed analysis is undertaken here to correlate observed pulse shapes with those expected on the basis of the switching speed and to assess what limitations may exist.

Consider a laser cavity uniformly filled with energy. This is nearly true since both mirrors are 100% reflecting and the Q switch pulses are long compared to the cavity round trip time. When the PTM switching action begins, a tube of light of constant intensity I_0 and temporal length $2t_1$ is approaching the Glan prism/Q switch combination. The intensity of the PTM pulse, $I_T(t)$, as a function of time can be written as

$$I_T(t) = T(t)\, I_c(t)$$

where $T(t)$ is the transmission out of the cavity as a function of time and $I_c(t)$ is the intensity of the beam in the cavity as a function of time.

For $$0 < t < 2t_1$$

$$I_c(t) = I_o$$

so that $$I_T(t) = T(t)\, I_o$$

and for $$t > 2t_1$$

$$I_c(t + 2t_1) = I_c(t) \{ 1 - T(t) \}$$

and

$$I_T(t + 2t_1) = T(t + 2t_1)\, I_c(t) \{ 1 - T(t) \}$$

The pulse shape is easily calculated from these recurrence relations. Pulse shapes were calculated for T_0/t_1 in the range 1 to 50, and some examples of these are given in figure 5.

Note that for $T_0 \leqq 2t_1$ the PTM pulse has the same peak power as the (internal) Q switched pulse. For $T_0 > 2t_1$ the peak power in the PTM pulse is less than the Q switched pulse. This sampling factor, the ratio of PTM peak power to Q switch pulse peak power, is plotted in figure 6.

5. PEAK POWER OF THE PTM PULSE

As mentioned in Section 2 the Q switched pulse shape depends on gain, loss and cavity length . If in a multimode laser where the diffraction losses are not a strong function of cavity length, but rather determine only the number of transverse modes operating, the pump energy and hence the inversion are held constant then the pulse width is directly proportional to the cavity length (or t_1). In view of this and since the output energy is also constant under these conditions, the peak power of the Q switch pulse is inversely proportional to the cavity length. For switching times $T_0 \leqq 2t_1$ the PTM pulse has the same peak power as the Q switch pulse, so for long cavities the peak power in the PTM pulse is also inversely proportional to cavity length and the product of FWHM and peak power, that is the energy in the pulse, is constant. If the switching speed T_o is long compared to the cavity transit

time t_1 , the peak power of the PTM pulse is less than that of the Q switch pulse and one can define a sampling factor

$$\text{Sampling Factor} = \frac{\text{Peak Power of PTM pulse}}{\text{Peak Power of Q switch Pulse}}$$

This sampling factor is plotted in figure 7.

6. MEASUREMENTS OF PULSE WIDTH AND PEAK POWER.

Figure 8(a) shows the experimental values of the relative amplitude and pulse widths of Q switched pulses for various cavity lengths (given in centimetres

in the upper right corner of each trace). The data were obtained with a diffuser and vacuum photodiode and displayed on a Tektronix 519 oscilloscope. The diffuser and photodiode were initially set for full scale deflection at the shortest cavity length then left undisturbed.

Figure 8(b) displays the relative amplitude and widths for the PTM pulses under similar conditions.

In figure 9 the FWHM obtained from the experimental data of figure 8 are plotted against cavity length together with calculated values for the PTM pulse. Agreement is good even for the simple model used. Similarly the relative peak powers derived from figures 8(a) and 8(b) are shown in figure 10 plotted double logarithmically together with a line of slope -1, confirming the predicted inverse dependence on cavity length.

For each measurement the cavity mirrors had to be moved and realigned and the delay adjusted for the PTM pulse; in view of this the scatter in the results is understandable.

A further comparison between a conventional and a PTM laser is given in figure 11 . Here the top trace represents a Q switched pulse with the dump circuit not operating, whilst in the middle trace the truncated Q switch pulse is shown for the case of the dump circuit in operation. Note that there is approximately 5 ns jitter in the timing of the dump switching. The bottom trace shows the PTM pulses, where very little amplitude jitter is seen. The timing jitter does not affect the PTM pulse as the Q switch pulse is relatively flat for a period much greater than the jitter.

For the above measurements it was found convenient to use a 10% transmission mirror in order to monitor the Q switch pulse. This had little effect on the PTM pulse measurements and was found to be a useful monitor of performance.

7. MEASUREMENT OF OUTPUT ENERGY

Many of the initial energy output energy measurements were subsequently discovered to be in error. It was found that as the pump energy was raised an increasing amount of the Q switch pulse energy leaked from the side of the cavity. This was not easily detected as the photodiode was adjusted to sense the fast PTM pulses. The Q switch pulse leakage was of barely sufficient amplitude to trigger the oscilloscope but because of its much greater width it can contain a significant amount of energy. This leakage could be minimised by careful alignment of the Q switch with the dump circuit inactive. (A similar problem occurs in measuring Q switched pulses in the presence of pre-lasing breakthrough).

To obtain a correct measure of the PTM pulse energy, two measurements were necessary. First the leakage was measured with the dump circuit inactive, then the total energy was determined with the dump circuit operating.

As shown in figure 11, once the dump circuit is fired the Q switch pulse is truncated. On this basis the PTM pulse energy would be equal to the total energy minus roughly half the Q switch pulse leakage energy.

In figure 12 the output energy for a 6 mm x 50 mm Nd:YAlG laser in a close coupled, silvered elliptical cavity is given for the following laser configurations:

(1) Normal mode operation with a 34% Tx output mirror and without the Glan or Q switch.

(2) Q switched output with a 34% Tx output mirror.

(3) PTM pulse energy with a 100% Rx mirror and a 97.5% Rx mirror.

At a pump energy of 14.4 J , the maximum value used, the relative efficiencies are:

Normal mode	-	2.6%
Q switched	-	0.67%
PTM	-	0.39%

The PTM pulse energy can be seen to approach saturation asymptotically. With the 100% reflectors needed to effect PTM operation, it is saturation which limits the output. In the normal mode saturation can be shifted to higher pump energies by using higher transmission mirrors.

8. THERMAL COMPENSATION

At the specified repetition rate of 168 Hz, thermal effects in the laser rod will cause depolarisation(ref.12) with subsequent loss of output.

One thermal compensation technique which was proposed by Scott and DeWitt(ref.13) is illustrated in figure 13. Two identical laser rods are used, separated by a $\lambda/2$ plate. The polarisation states are indicated by an arrow for polarisation in the plane of the paper and by a dot when the polarisation is at right angles to this. The technique is based on interchanging the radial and tangential components;what was a radial component in the first rod becomes a tangential component in the second. This system is cumbersome as it requires two identical laser rods and pump systems.

In principle the same effect could be achieved by splitting the system of figure 13 through the middle of the $\lambda/2$ plate, which would then become a $\lambda/4$ plate, with the mirror adjacent to it. The problem now is that the polarisation is rotated 90^o and on entering the Glan prism after passage through the system the light is rejected by the Glan. This is easily overcome by adding a third mirror at the side to reflect the light back into the system. Figure 14 shows such an arrangement together with the light path and polarisation states. Also shown in figure 14 is an additional Q switch found necessary to suppress pre-lasing at high repetition rates. Without this additional switch cross coupling of the polarisation states due to thermal birefringence meant that the resonator could be blocked at the dashed line A-A' of figure 14 and the laser would operate in the free running mode off the side mirror. Both Q switches need to be operated simultaneously to open the system but only Q switch 1 is switched by the dump circuit to give a PTM output. The system has other unique features which could be desirable under some conditions. For example if used as a straightforward Q switched laser, outputs from the mirrors are in different polarisation states as indicated in figure 14.

Ferguson et al(ref.14) have employed the same principle of separation of the polarisation states to achieve compensation. In their design a large block of calcite is used to spatially separate two beams on parallel paths. A single Q switch of large aperture accommodated both beams. Their design however does not give short pulses and is not amenable to PTM operation.

It was subsequently found that a three mirror design similar to figure 14 but without the additional Q switch had been used for a ruby laser by

Oettinger(ref.15) for different reasons.

The design was tested up to to a repetition rate of 50 Hz, the highest rate attainable at the time this work was carried out. Figure 15 shows the Q switch pulse amplitude at 6 Hz and 50 Hz for a normal laser configuration and for the folded configuration. A drop of approximately 30% is evident in the normal configuration at high rate and little or none occurs in the folded configuration. The pump energy was 11.9 J and the output mirror transmission was 73% (mirror R_1 of figure 14). This comparison could be accomplished by merely blocking or unblocking the side arm. In figure 16 the output pulse energy is plotted as a function of repetition rate. For the folded configuration the output energy shows some variation, but this is considerably less than in the conventional arrangement. The variations seen in the folded configuration are thought to be caused by changes in the resonator characteristics due to thermal lensing. No attempt was made in this investigation to correct for thermal lensing.

Although the scheme described above is capable of achieving thermal compensation successfully its use in the PTM mode restricted the output energy even further , since the beam passes through the rod four times per cavity round trip, saturation occurs earlier than in the normal configuration. In the latter an output energy of 50 mJ could be attained, figure 12, but in the folded configuration 35 mJ was the upper limit, occurring at 7.5 J input.

9. CONCLUSION

The investigation shows that the PTM laser can deliver pulses of short risetime and nearly ideal shape. Complications arise at high repetition rates where thermal compensation becomes necessary resulting in a reduction of the attainable output energy and in a more complex device configuration.

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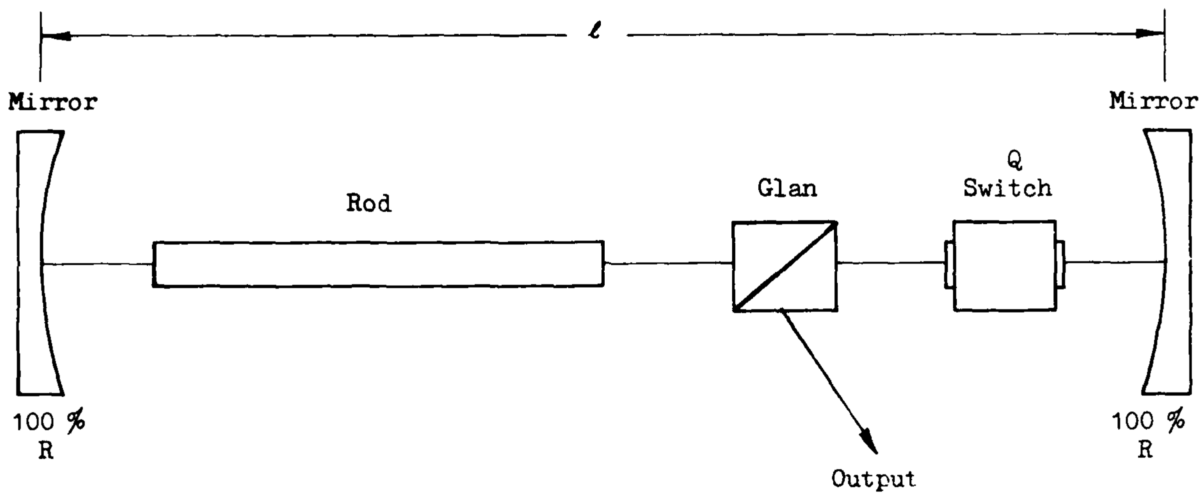


Figure 1. PTM laser

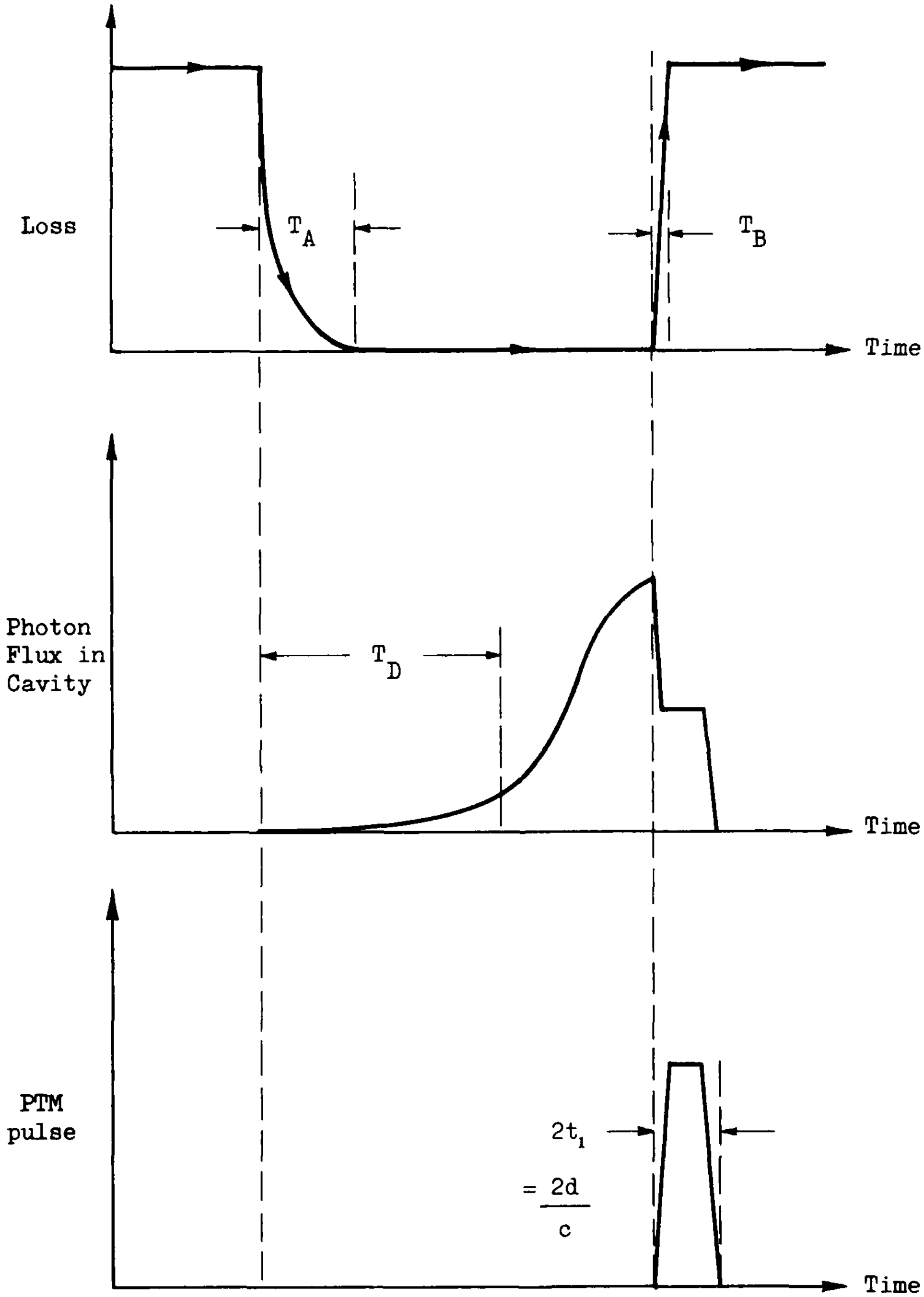


Figure 2. Switching sequence for PTM operation

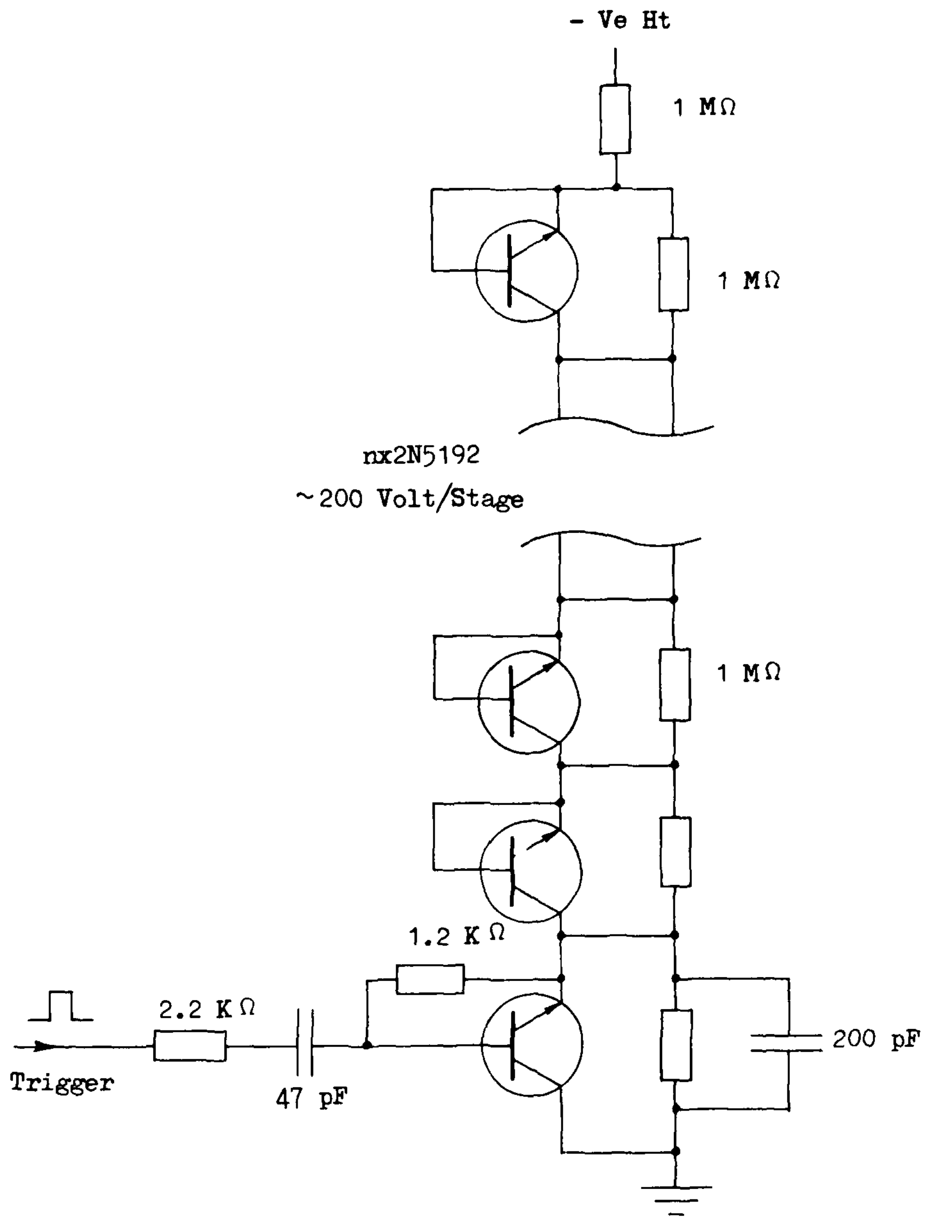


Figure 3. Avalanche transistor chain

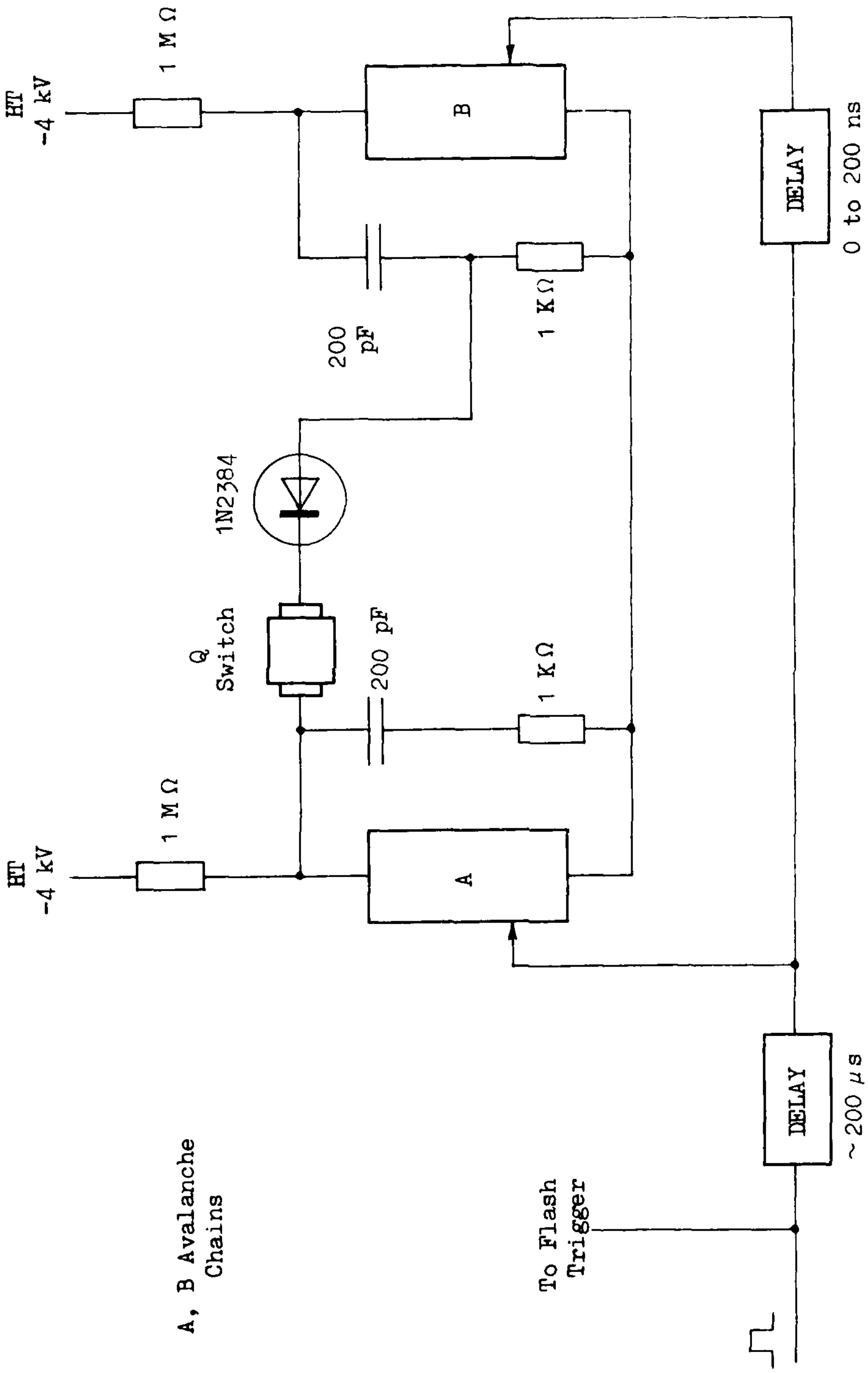


Figure 4. Avalanche transistor Q switch drive

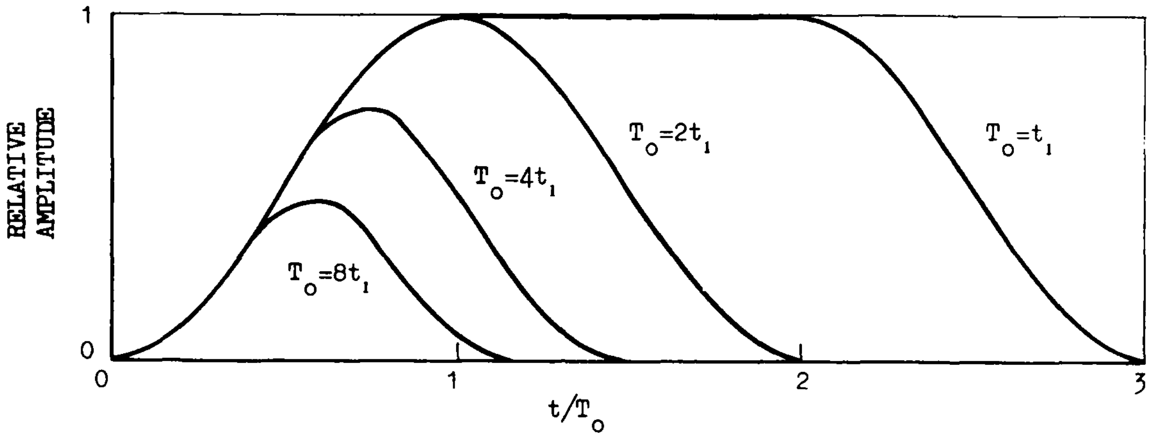
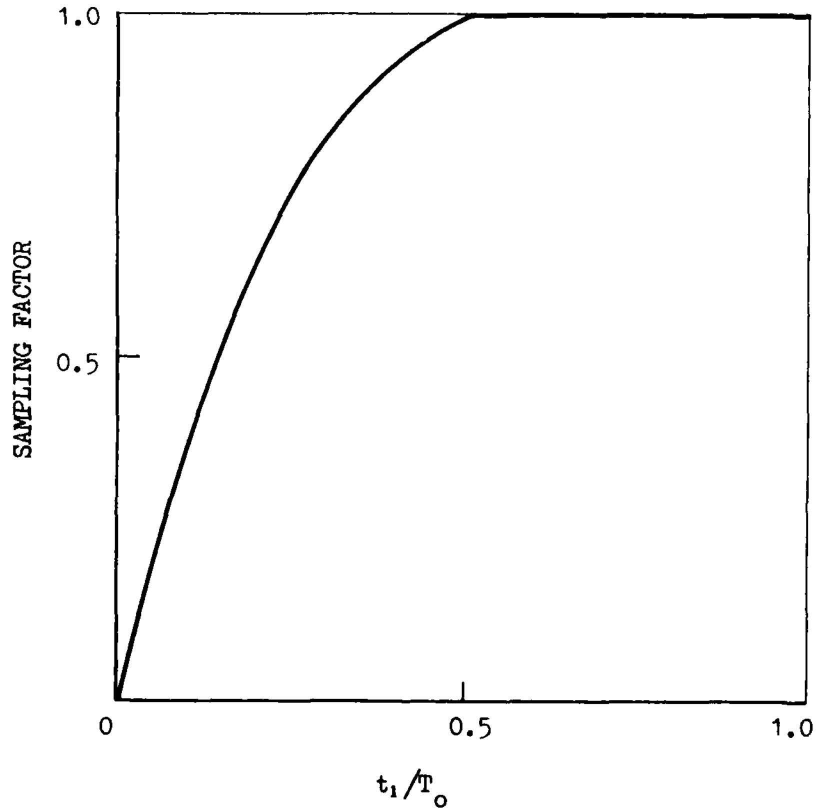


Figure 5. Calculated PTM pulse shapes



$$\text{Sampling Factor} = \frac{\text{Peak Power in PTM pulse}}{\text{Peak Power in Q Switch pulse}}$$

Figure 6. PTM pulse sampling factor

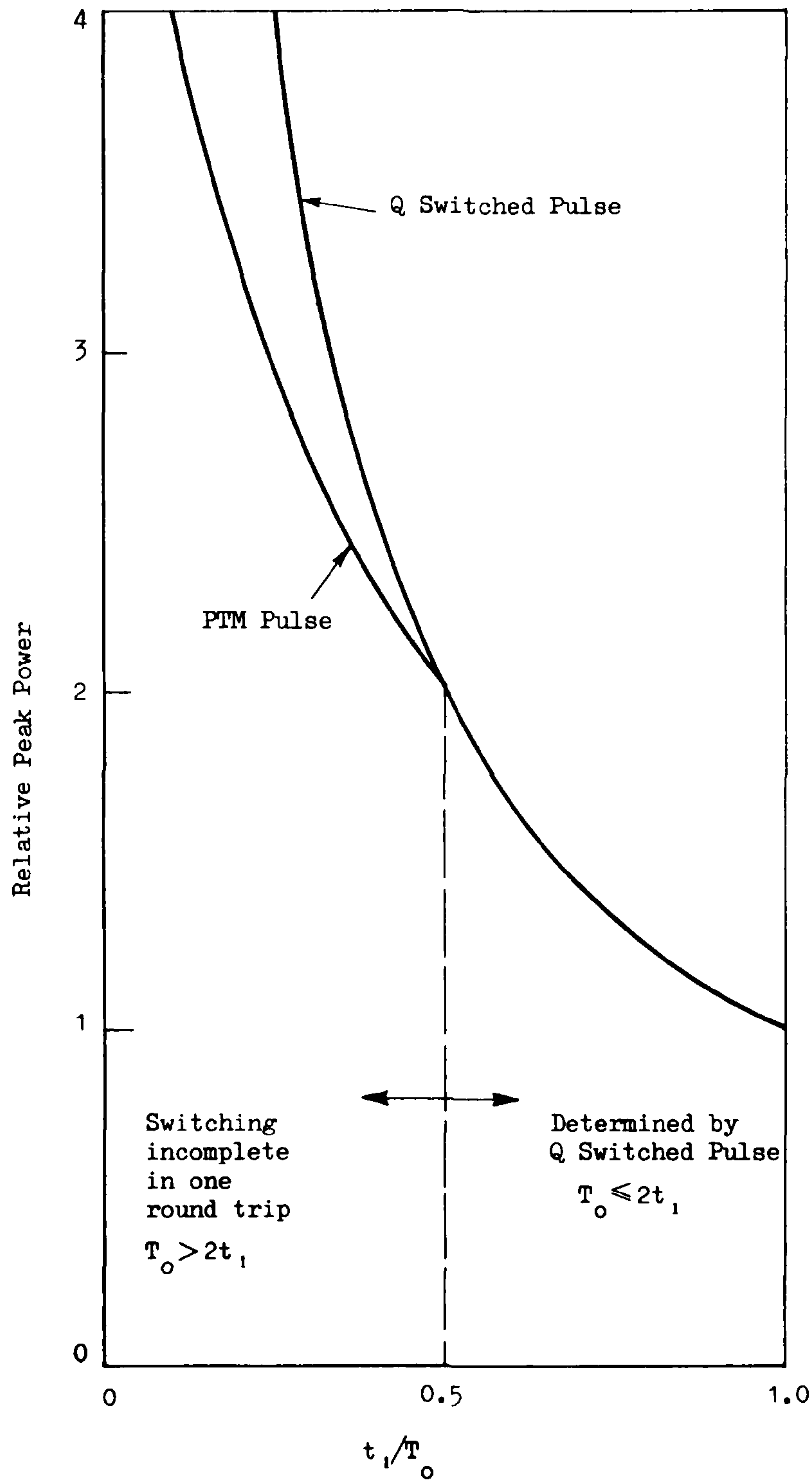
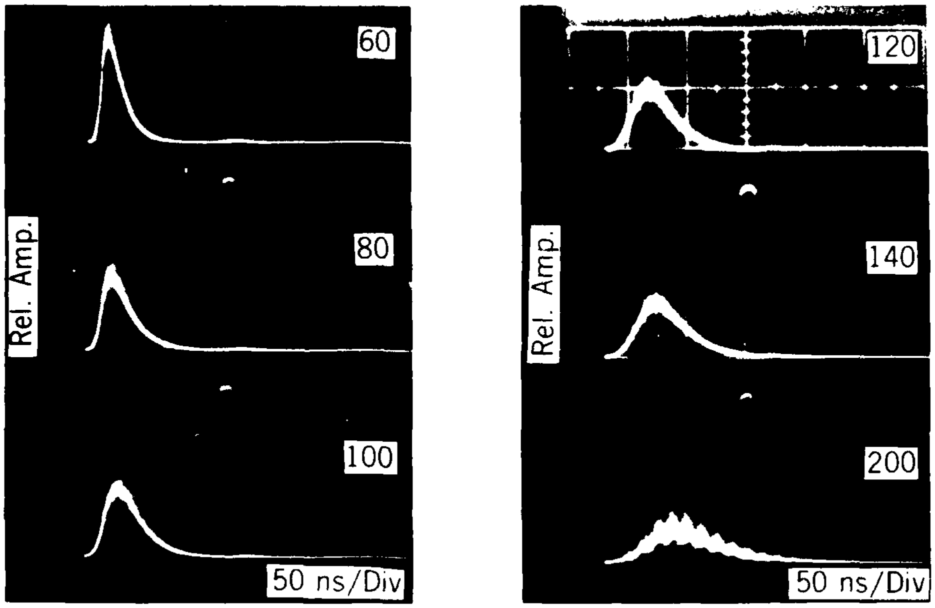
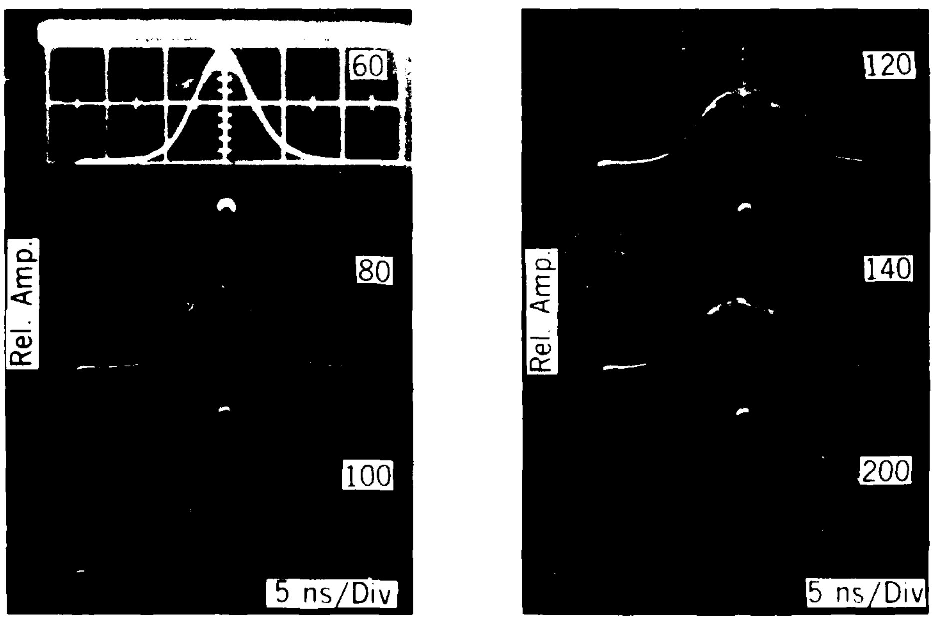


Figure 7. Relative peak power vs cavity transit time



(a) Q switched pulses



(b) PTM pulses

Figure 8. Relative amplitude and pulse widths

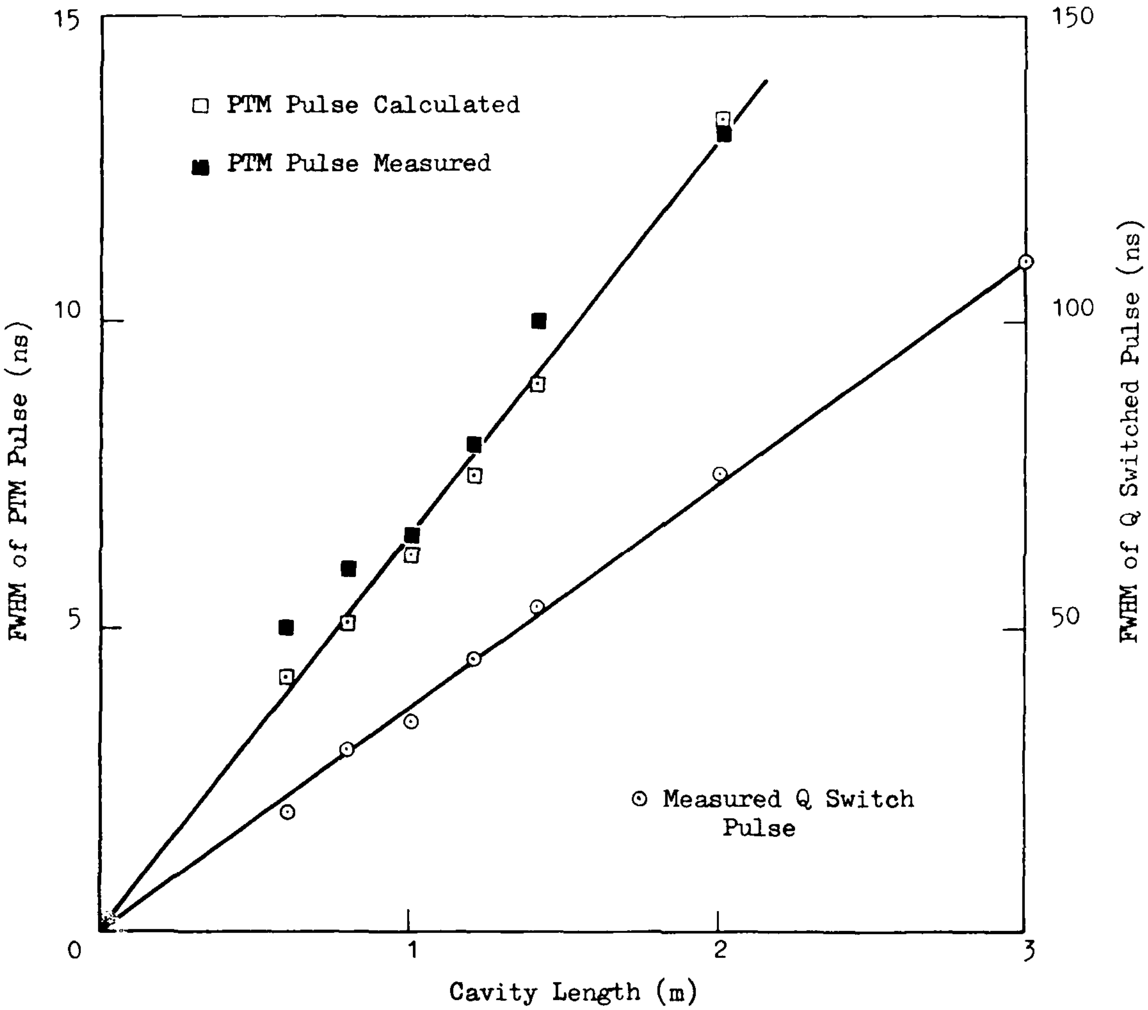


Figure 9. Pulse width vs cavity length

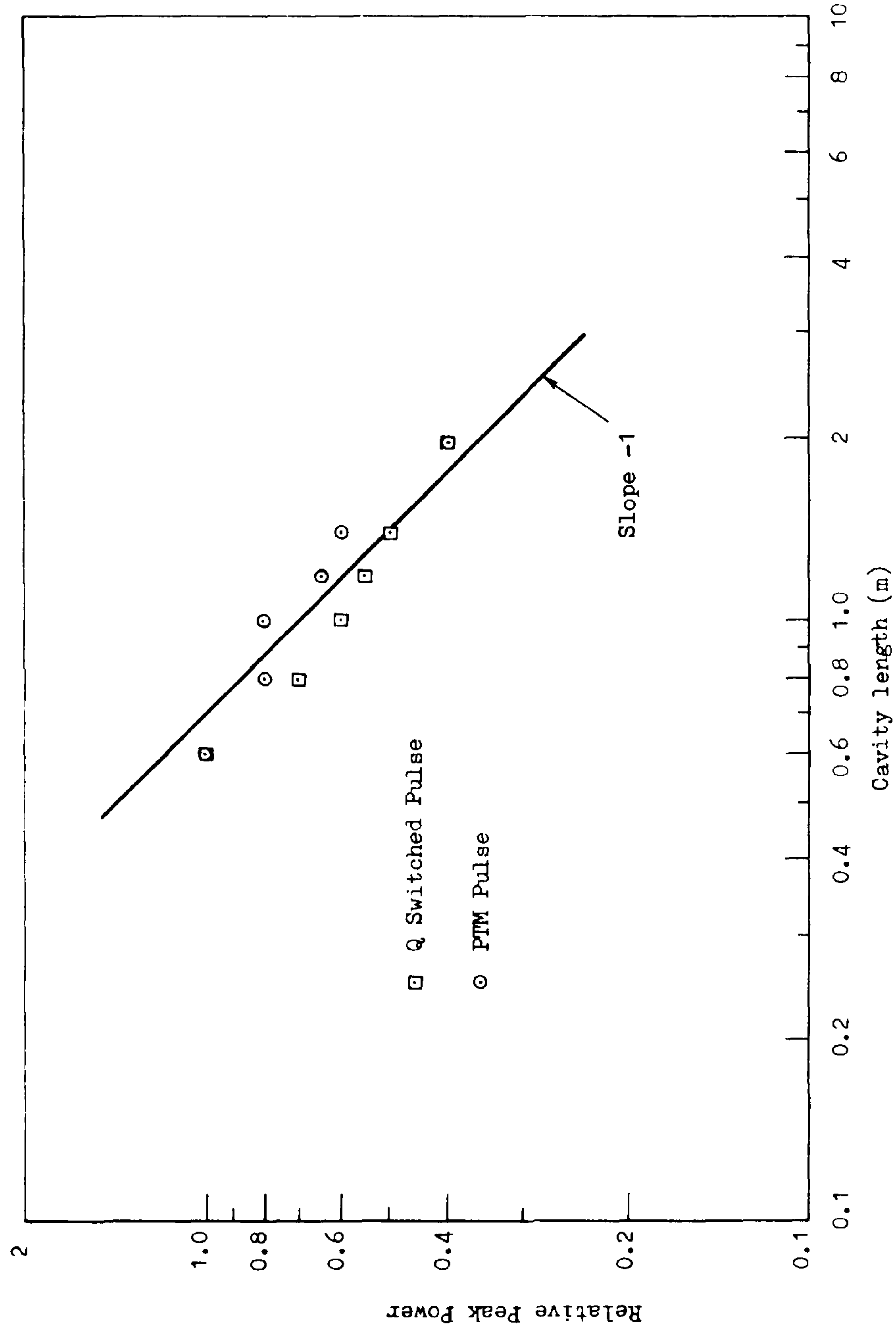
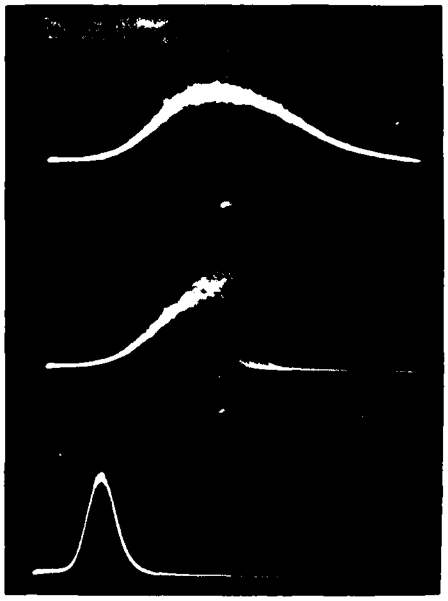


Figure 10. Relative peak power vs cavity length



Q Switched Pulse

Truncated
Q Switched Pulse

PTM Pulse

Horiz.: 10 ns/Div

Figure 11. Timing jitter on dump switch

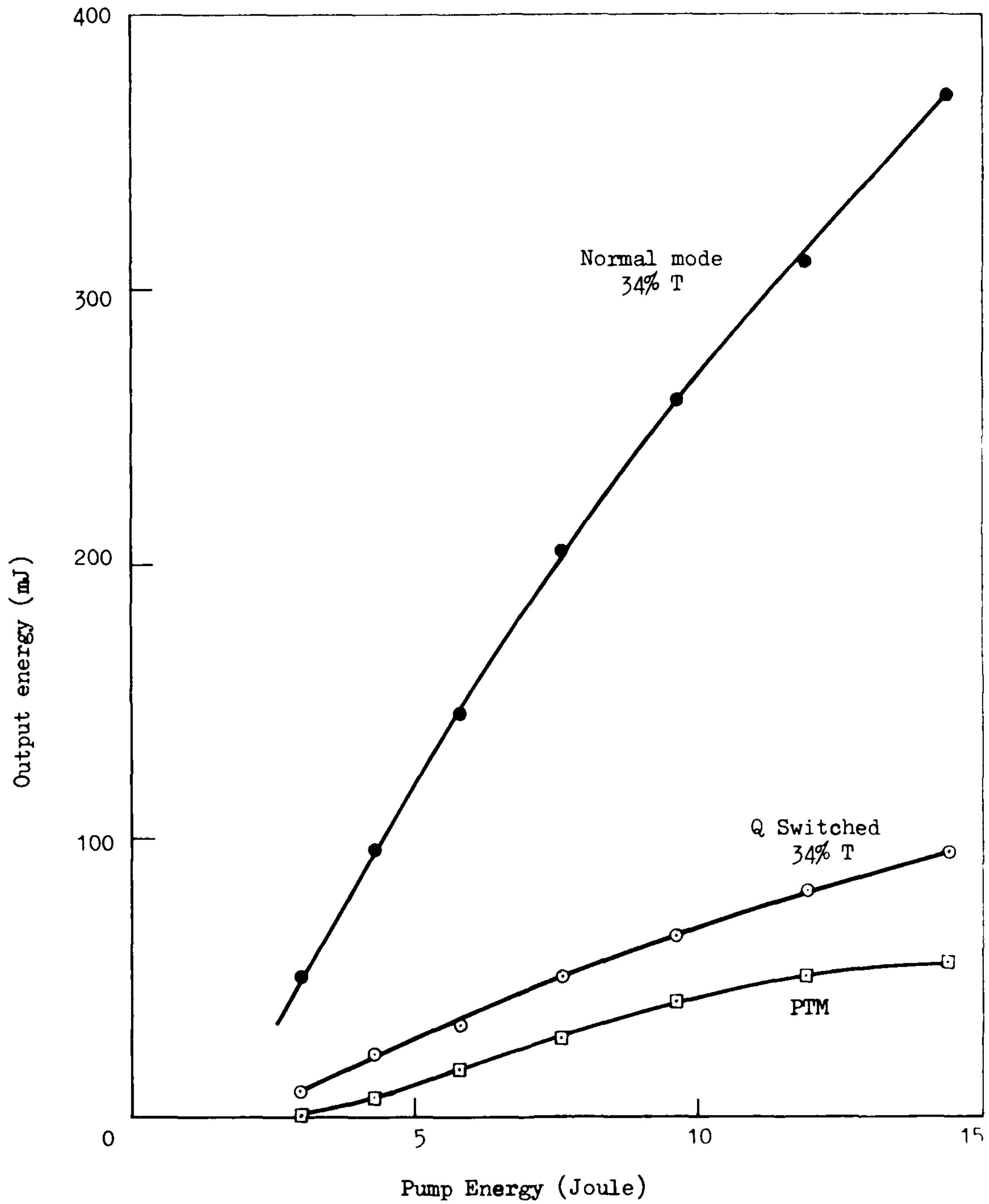


Figure 12. Output energy vs input energy

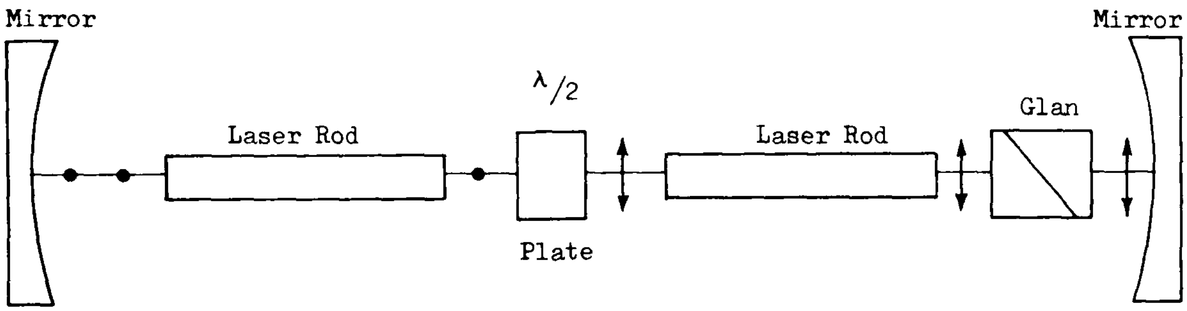


Figure 13. Scott and DeWitt's thermally compensated laser

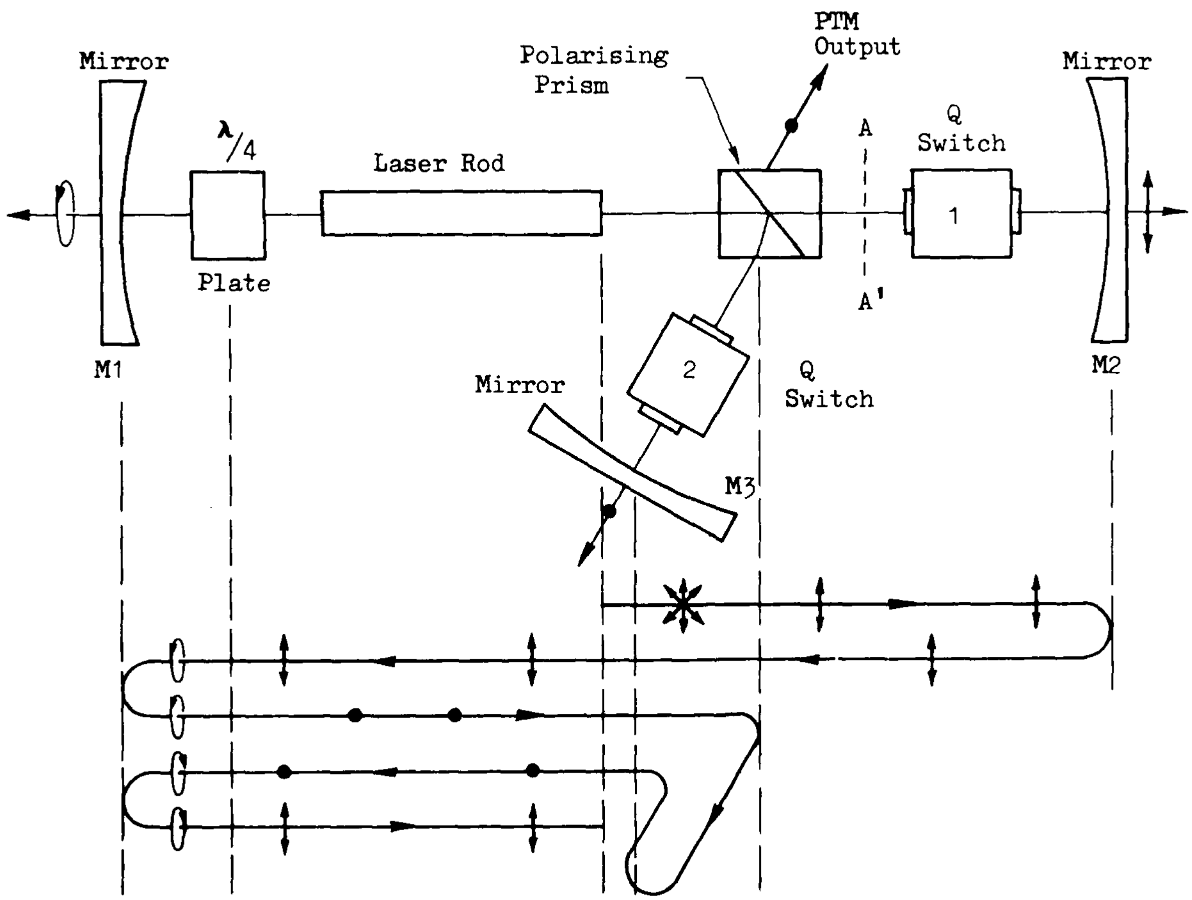
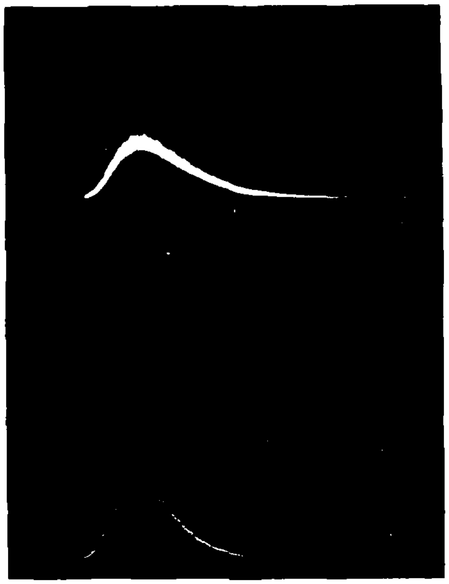


Figure 14. Folded thermally compensated laser

Q Switch as for folded

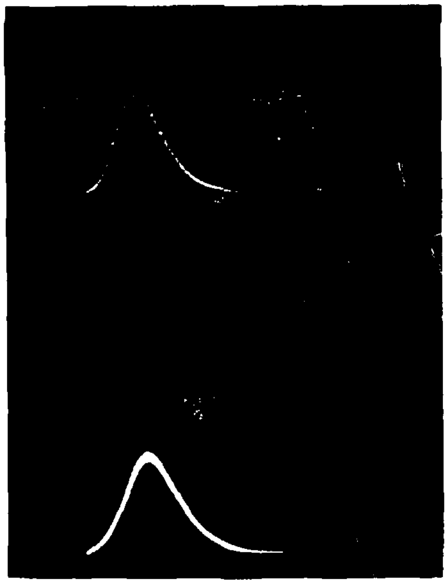


50 Hz

6 Hz

Horiz.: 20 ns/Div

(a) Normal configuration



6 Hz

50 Hz

Horiz.: [illegible] ns/Div

(b) Folded configuration

Figure 1[illegible]. Pulse amplitude at [illegible] Hz and [illegible] Hz

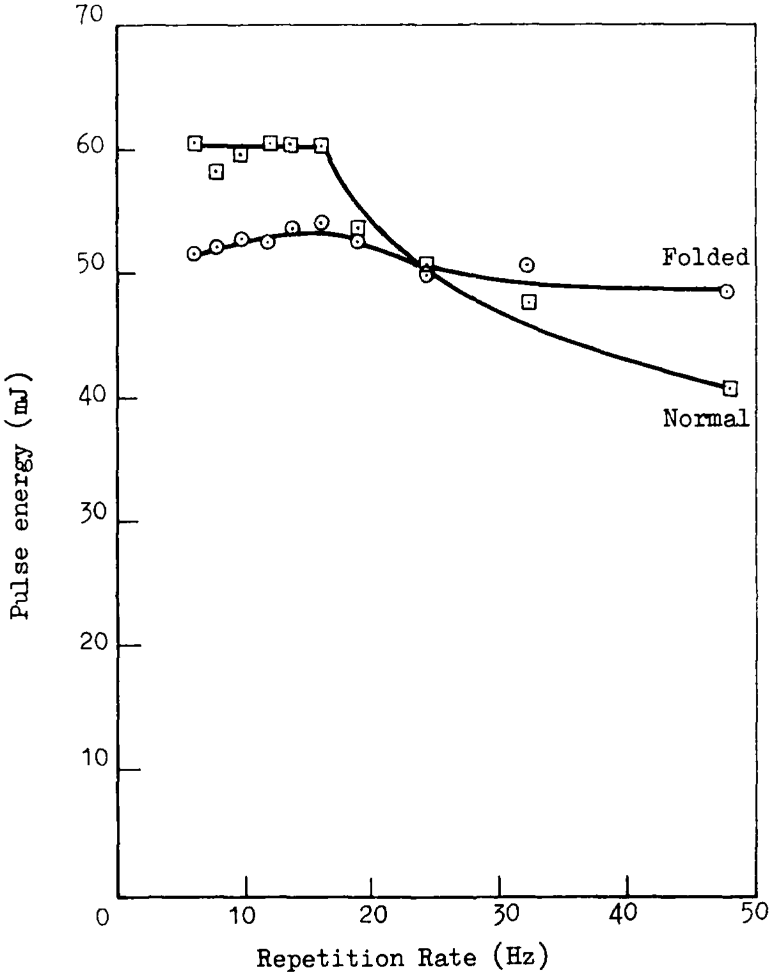


Figure 16. Pulse energy vs repetition rate

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